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ABSTRACT

This module discusses some of the objectives of incorporating vegetative cover in land treatment systems. Specific crops and forest cover are mentioned in relation to benefits associated with each, and specific treatment alternatives (irrigation, overland flow, and rapid infiltration) are included in relation to vegetative cover considerations. Waste treatment by land application rests on the ability of a given site to handle additions of both water and other waste constituents. A suitable vegetative cover enhances the capacity of soil to accept and renovate wastes through several means. Rooted plants protect the soil from erosion loss, encourage and maintain infiltration, accelerate soil drying through transpiration, absorb nutrients, produce economic benefits from crop harvest, and possess an aesthetic appeal. (Author/BB)

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Land Application of Wastes

An Educational Program

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ROLE OF VEGETATIVE COVER

Module 7

January, 1978

SE 025 021

LAND APPLICATION OF WASTES - AN EDUCATIONAL PROGRAM

The objective of this program is to increase the knowledge of engineers, scientists, waste management specialists and other practitioners in the concepts and principles needed to properly utilize the potential of land for the application of wastes. It is designed for individuals concerned with waste disposal alternatives for municipal, industrial, and agricultural wastes. The modules in this Program incorporate knowledge from sanitary and environmental engineering, agronomy, soil science, agricultural engineering, economics, and law.

The program consists of some twenty-five modules and audio-visual materials as appropriate.

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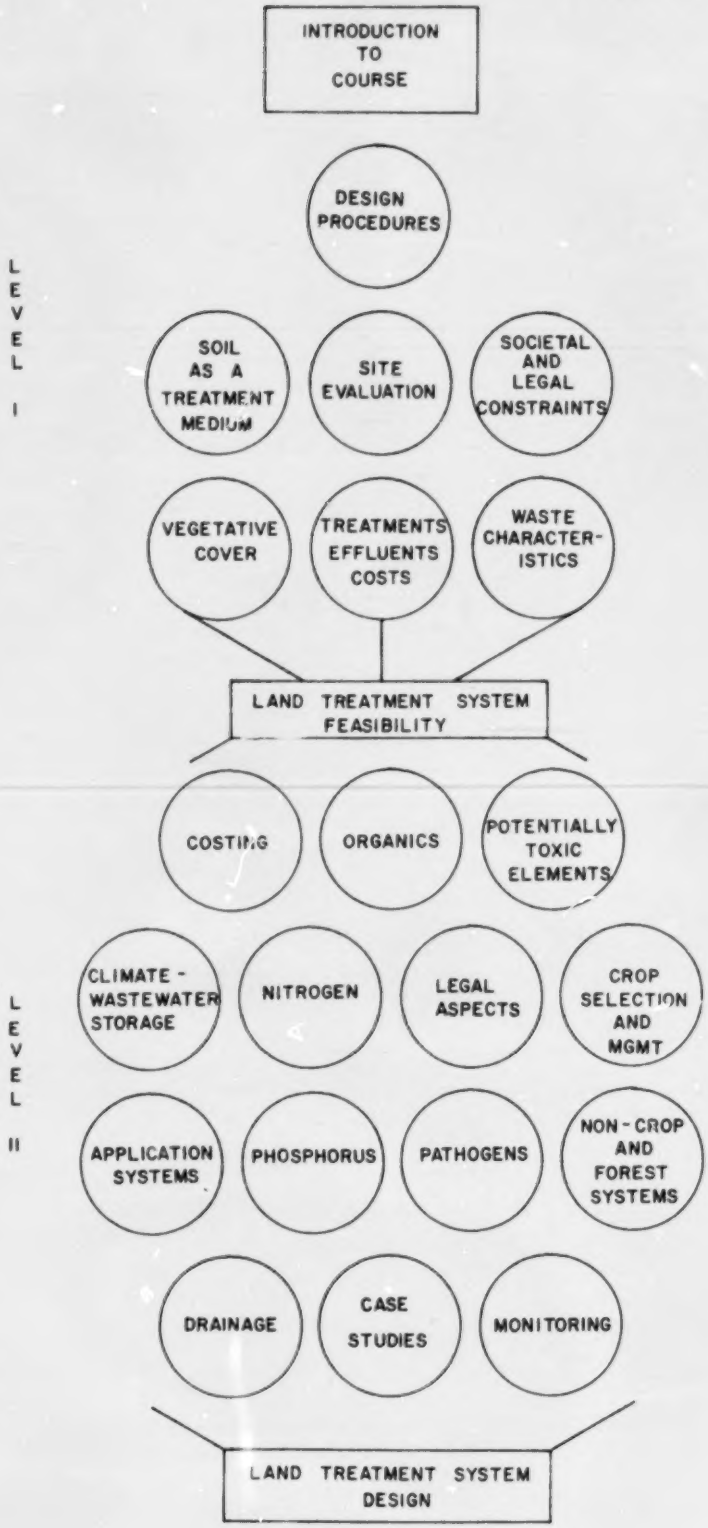

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ROLE OF VEGETATIVE COVER

Module 7

January, 1978

Summary

Waste treatment by land application rests on the ability of a given site to handle additions of both water and other waste constituents. A suitable vegetative cover enhances the capacity of soil to accept and renovate wastes through several means. Rooted plants protect the soil from erosion loss, encourage and maintain infiltration, accelerate soil drying through transpiration, absorb nutrients, produce economic benefits from crop harvest, and possess an aesthetic appeal.

This module discusses each of these objectives of incorporating vegetative cover in land treatment systems. Specific crops and forest cover are mentioned in relation to benefits associated with each, and specific treatment alternatives (irrigation, overland flow, and rapid infiltration) are included in relation to vegetative cover considerations.

"Role of Vegetative Cover" provides the Level I introductory treatment of this subject. Once this module has been completed, the Level II modules #20, "Crop Selection and Management Alternatives" and #13, "Non-Crop and Forest Systems" provide more specific information relating to vegetative cover, which will be useful to the design of land treatment systems. In particular, Module 20 discusses crop characteristics as they relate to land application, and specific topics dealing with crops, such as changes in their uptake of water and nutrients during the growth cycle.

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Glossary

colloid - Organic and inorganic matter in the soil with very small particle size and a correspondingly large surface area per unit mass.

eutrophication - A natural aging process of lakes whereby aquatic plants become abundant and dissolved oxygen becomes deficient. Usually accelerated by introduction of nutrients such as nitrogen and phosphorus from outside sources.

evapotranspiration - Discharge of water to the atmosphere by evaporation from the soil surface and transpiration from plants.

infiltration - Movement of water through the soil surface into the ground.

macropore - Space between soil particles large enough to allow flow of water under the force of gravity.

porosity - The fraction of the total volume of soil occupied by channels and pores.

Objectives

On completion of this module, the reader should be able to:

1. Name four types of vegetative cover.
2. Give five reasons why vegetative cover is important in land application systems.
3. Describe how different ways of applying wastewater to the land alter the ability of the vegetative cover to take up nutrients.
4. Cite the effects that the different kinds of vegetative cover have on evapotranspiration and infiltration.
5. Discuss the role of vegetation in nutrient uptake.

Introduction

Success in applying waste to the land depends on the ability of that site to handle water and waste constituents. A good cover of vegetation improves the soil's ability to accept and renovate wastes in several ways. One of the primary advantages of vegetative cover is its capacity to remove nitrogen from the soil. Since nitrogen loading per unit area is a limiting factor in the design and operation of the site, vegetative cover takes on major importance. Rooted plants also protect the soil from erosion and reduce the amount of runoff and pollutants carried by the runoff water. Vegetation encourages and maintains infiltration by adding to the organic matter content of soil, which is the prime agent for speeding up infiltration. Through the process of evapotranspiration, vegetation accelerates the drying of the soil, essential in maintaining odor-free conditions on the site. Vegetation at the waste treatment site increases public acceptance and can produce economic benefits. Crops and trees are more pleasant to look at than bare ground. Furthermore, renovated wastewater can be used to benefit a community, providing irrigation for greenbelts, city parks, golf courses, and other public areas.

Care must be taken in evaluating certain types of crops for use in waste application systems if significant numbers of pathogenic organisms or concentrations of potentially toxic elements are found in the influent waste. These considerations are seldom a serious roadblock to site development, but must be explored. These topics are discussed in Module 8, "Pathogens"and Module 11, "Potentially Toxic Elements".

Plant Cover Controls Erosion

Any waste application system must contend with the problem of erosion. The loss of soil particles means an accompanying loss of incorporated waste constituents such as phosphorus, pesticides, nitrogen and bacteria. This is particularly harmful when the particles lost are collodial, that is, extremely small ($\leq$ 0.002 mm) and having an electrical charge. These small particles of soil have the high surface area/volume ratio and electrical charge needed to attract charged waste constituents such as ammonium and metal ions and hold them in the soil matrix. Soil erosion is essentially the only way that fixed phosphorus is lost from a site, and because of the efficiency of phosphorus fixation in most soils, erosion control is very important in holding P losses to a minimum.

The waste absorbing abilities of the soil are reduced by erosion.

The impact of water dropping on bare ground initiates soil erosion. The beating action of the water displaces and disperses soil aggregates, causing individual particles to be carried off in surface runoff. And even if the detached soil particles are not carried away, they may form a hard crust upon drying which reduces infiltration of wastewater.

When the soil is covered with vegetation and decaying plant residues, the impact of water drops is cushioned and the chances of water detaching and carrying away soil particles is reduced.

Are all forms of vegetation equally effective? No. As shown in Figure 1, sod crops are most effective among common agricultural plants followed by rotations in which a series of crops are alternately grown, such as corn, wheat and clover. Small grains, such as wheat and oats, are the next most effective in preventing soil loss followed by row crops like corn.

Types of vegetation vary in their ability to prevent erosion.

Even though corn planted in rows is the least effective of common crops, it prevents

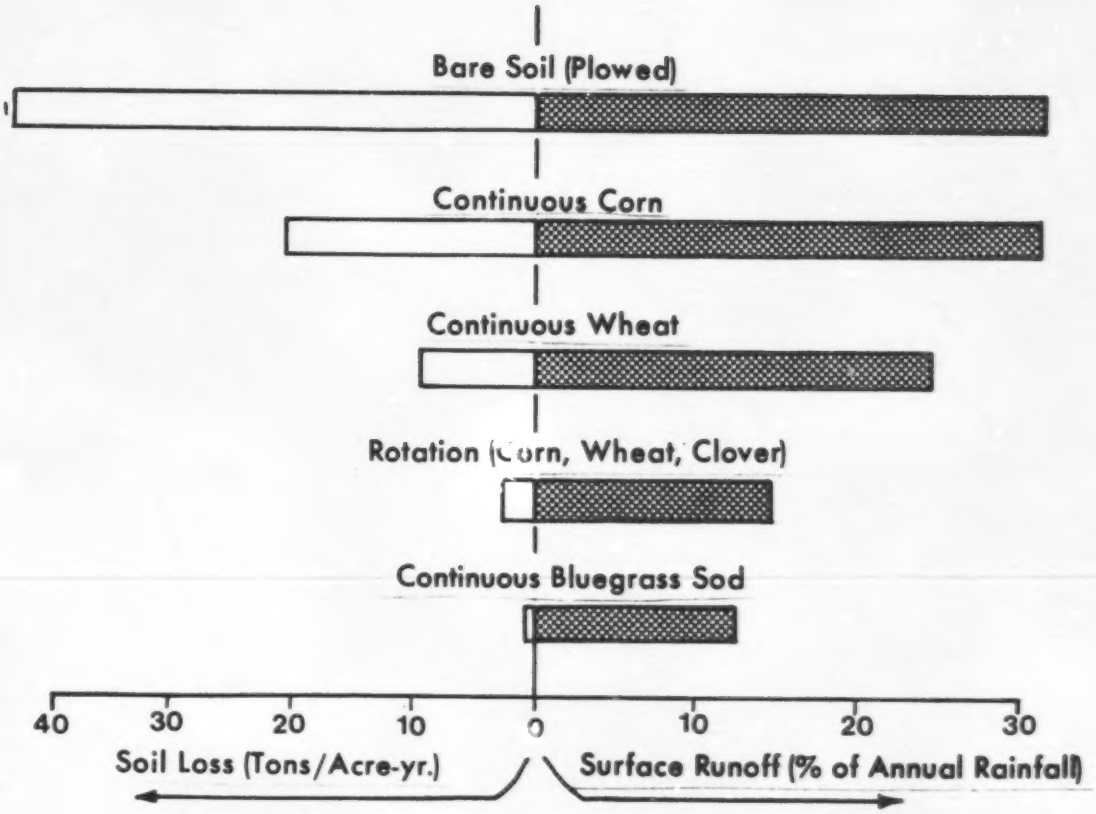


FIGURE 1. Cropping systems differ in ability to control surface runoff and erosion. These data are average annual values over a 14-year period on a silt loam soil (3.7% slope, 90 feet long). Average annual rainfall was approximately 40 inches. (adapted from Miller and Krusekopf 1932)

soil loss much more effectively than bare earth. The surface runoff from row-planted corn is similar to that of bare earth. However, the leaves and residues from corn reduce the impact of water drops and the corn roots physically hold the soil in place.

Sod Crops Give Advantages in Erosion Control

Sod crops, such as grasses and legumes, and forage grasses allow very little erosion and when planted densely, slow water runoff. This means there is more time for waste constituents and the soil to interact. There is less chance of flowing water cutting channels in the field. Uniform movement of wastewater over the soil surface is desirable to prevent short-circuiting.

Because of their greater density and more complete coverage of the earth, sod crops stop erosion at the same time they allow some surface runoff. This makes sod crops particularly suited to overland flow systems of waste application.

Sod crops are well suited to overland flow systems of waste application.

Traffic, Tillage Affect Infiltration

Vegetative cover speeds up the rate at which water enters the soil surface. The rate of entry, called infiltration, varies from one type of vegetation to another.

The way the crop is managed has a big influence on infiltration rates. For instance, corn and small grains planted in rows require extensive tillage which compacts the soil. Because there is up to a seven-month period between harvest and replanting, these crops also leave the soil exposed to the impact of rain drops for a significant time.

The way the site is managed affects the compaction of the soil, an important factor in infiltration.

When the site is planted in hay, there is less tillage and thus less compaction. Permanent pasture lands require infrequent or no tillage and when well managed these sites have moderately high infiltration rates. However, heavy grazing of pasture land can compact the soil just as heavy machinery can with row crops. The vegetative cover

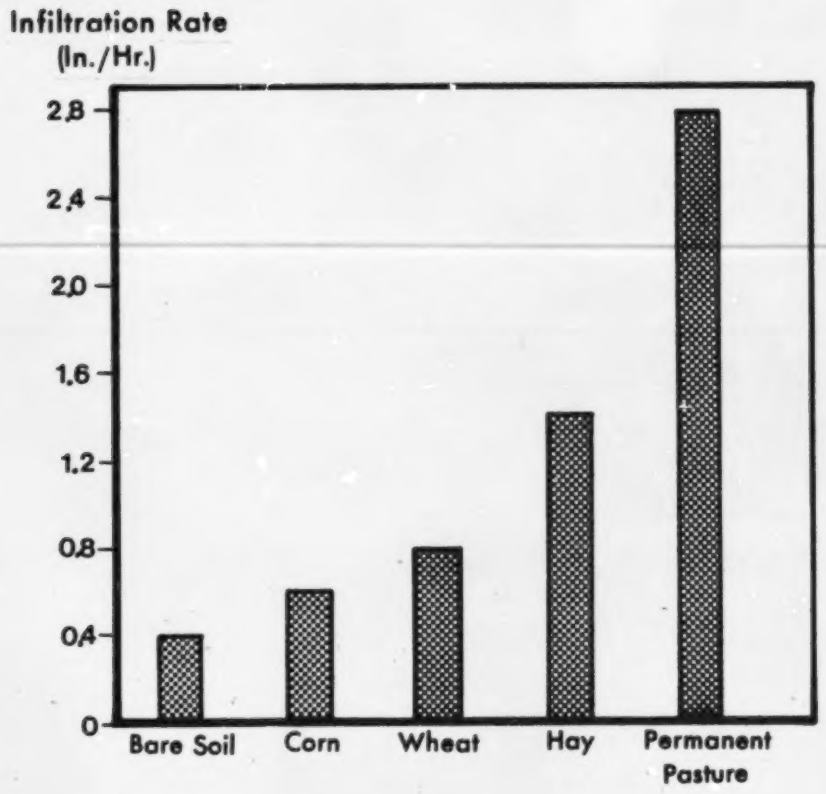


FIGURE 2. The type of soil cover markedly affects water infiltration rates. (adapted from Holtan and Kirkpatrick 1950)

with the best infiltration is undisturbed forest land. See Figure 2 for a comparison of infiltration rates under various types of vegetation.

Another influence on infiltration is the presence of organic matter in the soil. In fact, its presence in the soil is the chief agent for speeding up the infiltration rate. Under naturally occurring vegetation, much or all of the annual production of plant tissue is returned to the soil. Even with harvested crops, vegetative cover still adds considerable organic matter to the soil. For instance, corn produces an average of four to six tons of above-ground dry matter per acre, some of which is left on the soil surface. In addition, corn adds two to three tons of organic material per acre to the soil annually by its roots alone.

Organic matter in the soil is the prime agent for speeding up the infiltration rate.

Organic matter encourages the granular structure of the soil by increasing the proportion of macro-pores, especially in clayey soils. These large pore spaces transmit water readily in saturated soils in response to gravity. Granular structure is highly desirable for infiltration, particularly in loamy or clayey soils. See Module 3 "Soil as a Treatment Medium" for further discussion of soil structure.

Vegetation Influences Frozen Soil

Well aggregated soils that are high in organic matter freely accept water even when frozen. This porosity is due to the presence of roots and decaying plant residues in the soil. It may seem that frozen soils would be impermeable to water. On the contrary, some frozen soils have infiltration rates that equal or exceed rates when not frozen. But it is true that bare or compacted soils, which are low in organic matter, turn into concrete-like masses when frozen. (Trimble, et al., 1958).

Vegetative residues cause the soil to retain its porosity even when frozen.

Even though well aggregated soils may be highly permeable when frozen, it should be remembered that biological activity decreases drastically at low temperatures, and therefore, waste-loading rates often must be reduced or stopped in the winter.

Waste-loading still must be reduced in winter due to the decreases in biological activity.

Vegetation Aerates Soil

One of the most common obstacles to public acceptance of land treatment is a foul odor emanating from the site. The difference between no smell and an offensive odor is the difference between aerobic and anaerobic conditions. Aerobic conditions are needed for organic matter to decompose rapidly. These conditions can be maintained by scheduling the application of wastewater carefully so that the soil has a chance to dry between applications. These resting periods allow the soil to drain and aerate.

Vegetative cover hastens the drying of the soil, essential in maintaining odor-free conditions.

Vegetative cover introduces another way for water to be removed from the site besides evaporation, through transpiration. Loss of water through direct evaporation is limited to water at or very near the soil surface. The plant draws water from the soil, reducing the water content of first the surface layers and then successively deeper zones depending on the depth and density of the roots.

Plant roots absorb water and nutrients from the soil. The water moves upward through the plant body and is lost to the atmosphere from the plant leaves through transpiration. In this way, vegetation accelerates the drying and aeration of soils between wastewater applications.

Transpiration, like evaporation, depends on climatic conditions including temperature, precipitation, solar radiation, and wind. Transpiration also depends on the availability of soil moisture, and vegetation characteristics such as rooting depth and the seasonal pattern of both root and leaf development (Figure 3).

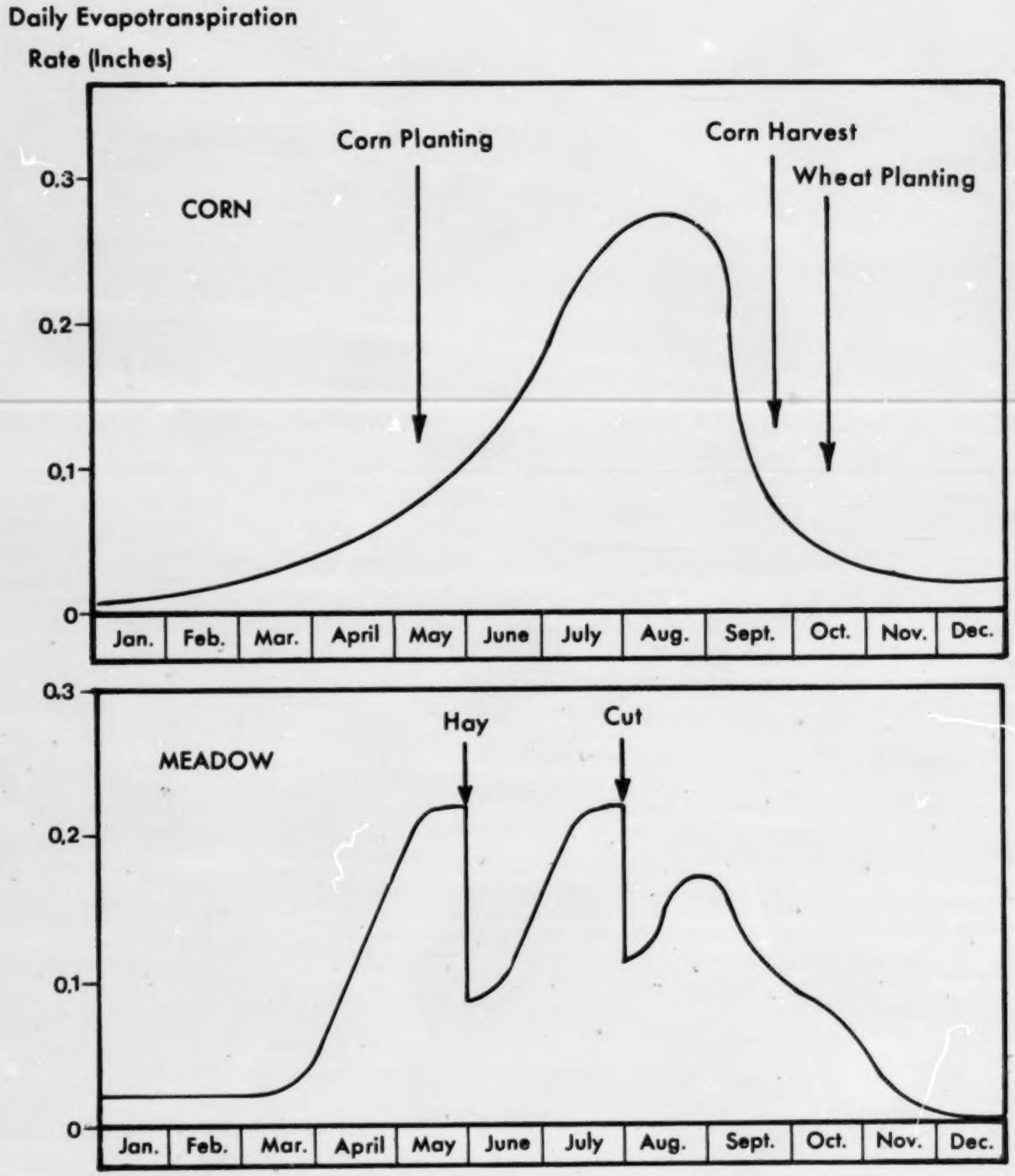


FIGURE 3. On irrigated land as shown here, evapotranspiration varies as a function of daily and seasonal energy inputs as well as the stage of crop development. These results are for similar soils and climatic conditions in Ohio. (adapted from Soil Conservation Service 1964)

It is not possible to separate the amount of direct evaporation and transpiration that goes on, so the combined value is called evapotranspiration (ET). This value can never exceed the maximum allowed by absorbed energy. Therefore, regional estimates of potential ET, applicable to most crops, can be calculated empirically or from heat budget studies. Evapotranspiration is discussed in Module 8, "Climate and Wastewater Storage". Also see Module 20, "Crop Selection and Management Alternatives" for methods of computing potential ET.

Vegetation Removes Elements from Waste

In irrigation systems, vegetative cover is the primary mechanism for nitrogen removal. Since nitrogen loading rates are a limiting factor in operating the site, vegetation takes on a prime importance.

Elements contained in municipal wastes and sludges can cause harm when discharged to bodies of water. Nitrogen and phosphorus, in excess, are the major causes of eutrophication in surface waters. Vegetative cover on the waste treatment site uses such elements as nutrients for growth.

Waste and sludge contain most if not all of the essential nutrients for growth, although not necessarily in the right proportions. Vegetation provides a sink for these and other nutrients, and thus plays another important part in the renovation of applied wastes. A sink is a term referring to loss from a system that cannot be measured. A sink might be a permanent or temporary holding place for pollutants and other elements and compounds. For instance, reed canary grass removes more than 350 pounds of nitrogen per acre annually.

Vegetation acts as an effective sink for nutrients when the crop is harvested and removed.

Phosphorus is not removed so readily. An acre of reed canary grass removes only 35 pounds of phosphorus per year; bluegrass removes only about 12 pounds of phosphorus. The removal of absolute quantities of nitrogen and phosphorus tend to differ by a factor of about 10, as shown in Figure 4. Figure 4 shows other types of vegetative cover and their removal rates.

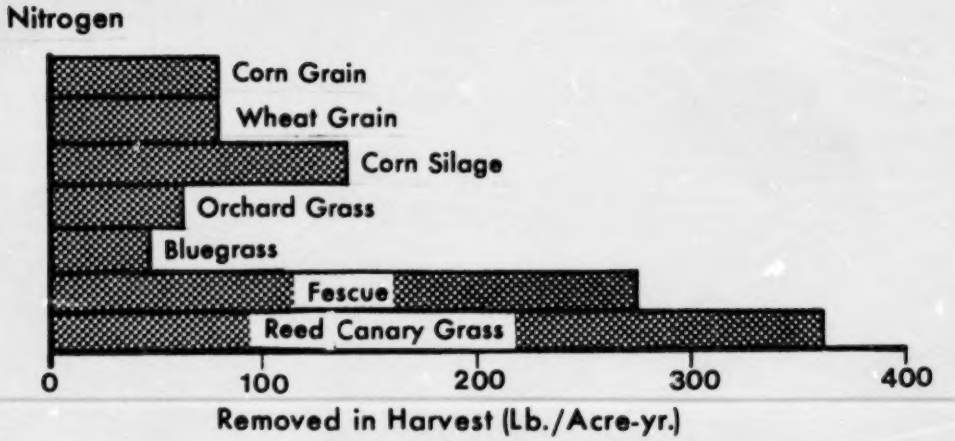
It is important to note that nitrogen is absorbed in greatest quantities by certain species of grasses. Grasses also are most effective in preventing erosion, promoting infiltration, and allowing for long periods of interaction between waste constituents and the soil-vegetative complex. Notable examples which have widespread usage in land application sites are reed canary and coastal Bermuda.

Grasses absorb the greatest amount of nitrogen, are most effective in preventing erosion, promote infiltration, and provide for a longer period of interaction between waste elements and the soil-vegetative complex.

Method of Harvest Influences Nutrient Uptake

Harvesting the entire above-ground parts of a crop removes more total nutrients from the soil than harvesting only selected portions of the crop. For instance, more nutrients are removed from the soil if corn silage is harvested than merely the corn grain. This is because decay of natural residues of the plant releases nutrient stores back into the soil, redepositing elements instead of removing them from the soil. The same is true of forest lands. In traditional harvest of forest land, only the stemwood is removed every 40 to 100 years. Trees take up as much nutrients as some agricultural crops do during a single growing season, but much of the uptake is redeposited. For example, an annual uptake of 80 pounds of nitrogen per acre by trees may result in only about 15 to 20 pounds of actual nitrogen retention per acre of forest. This is due to the large quantity of leaves, twigs, branches and roots which are left and release their nutrients back to the soil. Recent work (Bormann, Likens and

Harvesting the whole plant at frequent intervals removes more nutrients from the soil than merely harvesting selected parts of the plant at infrequent intervals.



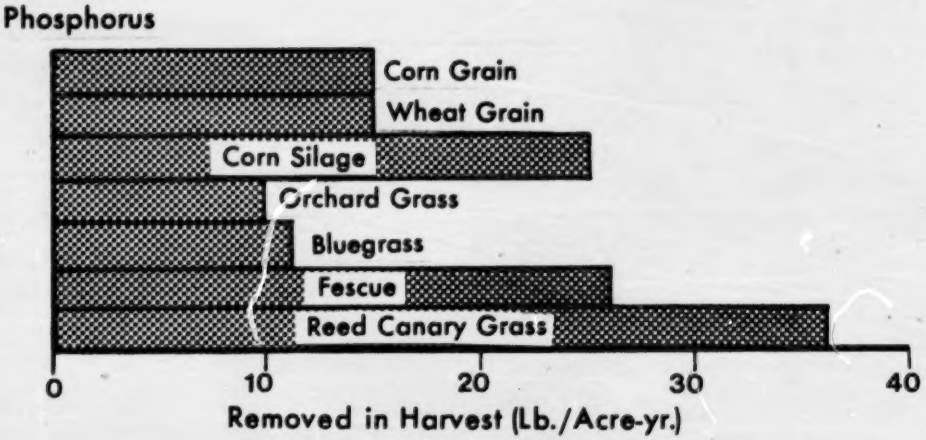


FIGURE 4. The relative amounts of nitrogen and phosphorus removed in crop harvest vary with the type of crop and the proportion of the tissue removed. Note that nitrogen and phsophorus scales differ by a factor of 10. (based on data from Hart 1974; Peterson *et al.*, 1973)

Melillo, 1977) indicates the possibility of a smaller proportion of nitrogen being returned to the forest floor than shown above, due to internal movement of the N from leaves back into the stems just prior to leaf fall.

Uptake Differs According to Form, Amount of Nutrient

Nutrient uptake is influenced by loading rates. For example, as shown in Figure 5, nitrogen absorption in selected grasses increases with fertilizer application rates. The relationship, however, is not linear, and the higher application rates result in a lower percent removal. Furthermore, when much of the applied nitrogen is in organic form as in sludges, it will not be available for plant uptake until after microbial decomposition. Thus, form as well as the total amount of plant nutrients must be considered when assessing their fate in the system.

Waste Treatment Methods Influence Nutrient Uptake

Different ways of applying waste to the land result in more or less nutrient uptake. When crops are irrigated with wastewater, harvesting of the plants removes nutrients and renovates the waste. The amount of wastewater application is dictated by the nitrogen requirements of plants.

Different waste application systems affect the amount of nutrients the soil will take up.

In overland flow systems, both crop uptake and denitrification play major roles in nitrogen removal. Phosphorus removal, however, may depend heavily on vegetative uptake because in overland flow systems wastewaters have only minimal contact with the soil.

Under the rapid infiltration system of land application, there is very little or no uptake of nutrients by vegetation because of the relatively short period of interaction between wastewater and the soil-vegetative complex. The amount of nutrients removed from wastewater is minor compared to the total loading rates. In this system, the main advantage of vegetative cover is that it increases infiltration rates.

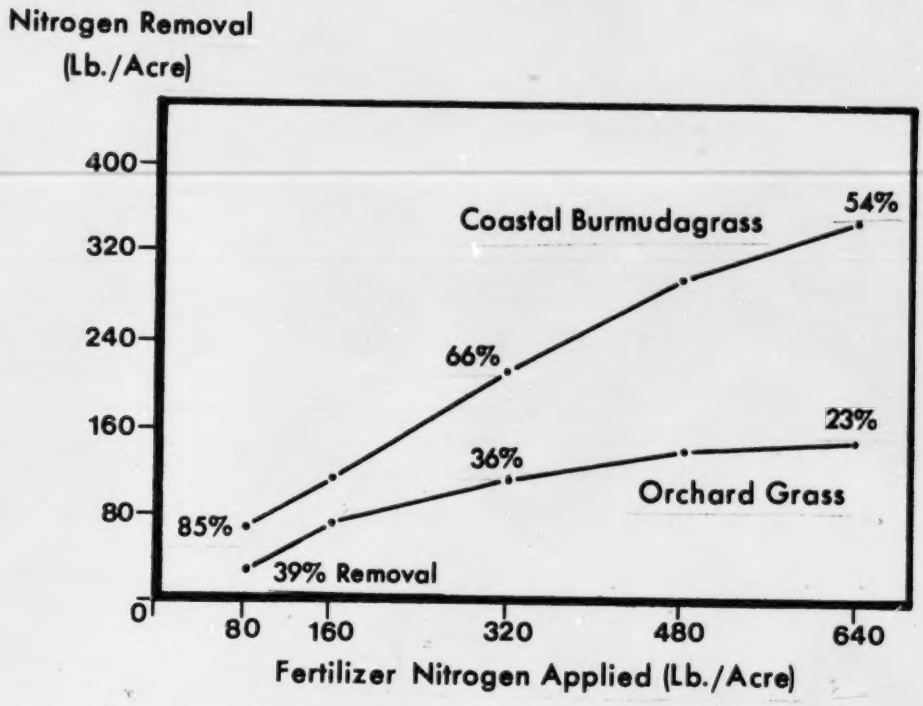


FIGURE 5. Nitrogen removal by grass is in part a function of application rate as well as growth capabilities of the species. The inserted numbers indicate the percentage of applied fertilizer nitrogen removed at each level. (adapted from Burton et al. 1963; Dotzenko 1961)

Forest Land Offers Possible Waste Management Site

As stated earlier, forest land is not the best site for taking up nutrients after application of waste. This is because only the stemwood is removed at infrequent intervals with much of the plant residues returning to the soil. However, undisturbed forest land is the best vegetative cover for promoting infiltration.

New methods of harvesting forest lands offers hope for forests as land application sites.

New methods of harvest offer hope for forest lands as waste application sites. If the entire above-ground crop of trees is chipped and removed at shorter intervals such as every five to 20 years, more nutrients are taken up from the soil. The potential for combining waste application with wood and pulp production using such techniques is discussed in Module 12, "Non-Crop and Forest Systems".

Crops, Livestock from Site Can Produce Revenue

Direct sales of crops and livestock or leasing of irrigated lands to local farmers produces incomes. In either case, prices and crop yields will vary geographically and should be determined from local sources.

The sale of annual crops such as corn grain generally produces a higher return than perennials such as hay. However, annuals usually require greater inputs of labor and equipment as well as a higher level of agronomic expertise.

The return on crops from existing land treatment systems offsets only a part of the overall operation and maintenance expenses. Returns from the sale of hay at a food-processing plant in Paris, Texas, contributed only 8 percent of the operation and maintenance costs (Gilde, et al., 1971). The Werribee Farm in Australia recovers about 12 percent of its costs from the sale of livestock, raised or fattened on irrigated pasture land (Hary, 1974). Estimated crop return for 1975 from

the Muskegon, Michigan, facility is about $1,000,000. This offsets a significant portion of the annual operation and maintenance expense.

Vegetative Cover Has Aesthetic Appeal

Most people find a planted area better looking than bare ground or a weed patch. The appearance of the waste application site will probably affect public acceptance of its presence in the community. Vegetative cover might be selected with an eye to aesthetic appeal as well as utility.

For example, the problem of aerosol drift from sprinkler systems could be reduced by border strips of trees or tall shrubs. Using wastewater to irrigate existing vegetation on golf courses or highway greenbelts is another alternative. Attractive vegetation at a waste treatment site is an alternative to regarding the site as a nuisance, a place to hide from public view.

Using Reclaimed Wastewater Appeals to Public

In many communities, treated wastewater is used to irrigate greenbelts, parks, golf courses, highway median strips, college and university grounds, and cemeteries. San Francisco's 800-acre Golden Gate Park is irrigated by fixed sprinklers with one-third of the water produced by one of the city's water reclamation plants. Especially in arid regions, reclaimed wastewater is cheaper to use than potable water for these purposes. For instance, in Laguna Hills, California, reclaimed wastewater is used to irrigate a golf course, fill animal water holes at a safari park, irrigate crops, and irrigate a 295-acre greenbelt. The golf course buys this reclaimed wastewater at $47 an acre-foot. This compares to the price of domestic water at $78 an acre foot. (EPA, 1973).

There are several successful wastewater irrigation projects for parkland, greenbelts, etc. In arid areas, reclaimed wastewater can be purchased much cheaper than potable water.

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THE ROLE OF VEGETATIVE COVER

Objectives

Upon completion of this module, the participant should be able to:

1. Indicate four types of vegetative cover.

2. Indicate five reasons why vegetative cover is considered important in land application systems.

3. Cite general differences among the types of vegetative cover in their effect on either evaporation or infiltration.

4. Indicate the effect of different types of application systems on nutrient removal by the vegetative cover.

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THE ROLE OF VEGETATIVE COVER

Module 7

January, 1978

THE ROLE OF VEGETATIVE COVER

(Slide 1) This Level I lesson concerns the role of vegetative cover at a land application site. In the box that contained the tape and the slides is an envelope labelled "Objectives", (Slide 2). The list of objectives for this lesson is in the envelope. Find and study the objectives. When you have finished turn the recorder back on. You may keep the objectives for reference during this lesson.

The purpose of land application is to treat a quantity of wastewater or sludge so that the effluent is of acceptable high quality. A plant cover, (Slide 3), contributes to this process by maintaining the soil structure and preventing erosion, by maintaining adequate infiltration rates, and by taking up waste constituents. The vegetative cover may provide cash return to help defray maintenance costs plus it is aesthetically pleasing.

There are 4 basic types of cover crops that will be considered in this unit. These are sod, row crops, small grains and forests. The type in Slide 4 is a sod cover. A sod cover refers to grasses such as timothy or legumes such as alfalfa. Sod can also be a mixture of grasses and legumes. This type of cover is used for pastures, golf courses, and hay production.

The type in Slide 5 is a small grain cover. This can be any type of small grain like wheat, oats, or barley. These are usually planted in rows less than a foot apart. Often only the grain is harvested, but the stalks make excellent straw and can also be harvested. A third type of vegetative cover is a row crop, like corn or beans, planted in rows from 15 to 30 inches apart, as in Slide 6. Oftentimes, sod, small grains, and row crops will be planted successively in a cycle, say five years for the cycle. This is called a rotation. A fourth type of vegetative cover that we will mention in this module is forest. This can be a natural mixed species forest or a planted forest of a single species of trees. Slide 7 shows this form of cover.

Vegetative cover has a profound effect on the soil as indicated in this slide series (Slides 8 through 17). Both soils in these boxes were of similar texture. A heavy rainfall was simulated on each soil. Notice the effect of the precipitation on the bare soil and on the sod covered soil. The rain beating on the bare soil tends to break up the soil aggregates and displace

and disperse soil particles. This allows individual particles to be transported in runoff. The sod and the decaying plant residues tend to act as a cushion to absorb drop impact, preventing soil particles from becoming detached.

The different kinds of vegetative cover vary in their ability to prevent erosion. Slide 18 graphically shows this. Notice that ground planted in corn, perhaps the least effective row crop, experiences half the soil loss of bare ground. Corn does not provide complete soil coverage, but the leaves and residues reduce drop impact while the roots physically hold the soil together. The ability of sod crops to prevent erosion makes them particularly suitable for overland flow systems of waste application (Slide 19). Dense sod also reduces the velocity of runoff, allowing time for interaction between waste constituents and the soil-vegetation complex. The tendency of channelized flow is also reduced, promoting more uniform movement of wastewater over the soil surface.

The effect of vegetative cover on infiltration rates is closely related to the effect on erosion (Slide 20). Did you notice that the container with the bare soil had more runoff than the container with the sod? The differences between the two indicates the difference in infiltration. Slide 21 shows a graph of infiltration rates for bare soil and several types of vegetative cover. Absolute values will vary with soil properties and topography although relative differences among types of vegetation are fairly constant. The soil properties that affect infiltration are presented in detail in Module 3, "Soil as a Treatment Medium".

Cover conditions which produce the greatest protection against erosion generally have the highest infiltration. This is, in part, a function of management operations. Row crops and small grains commonly require extensive tillage (Slide 22) which may lead to compaction of the soil. Slide 23 shows this. In addition, because of the exposed soil surface between the rows while the plants are small, the soil is exposed to raindrop impact for a significant period of time. This also results in compaction of the surface soil. The problems of erosion and compaction can be reduced a great deal by new tillage methods. New tillage methods reduce the number of passes required over a field and generally improve the infiltration rates over traditional

methods for row crops and small grains. These new methods include the elimination of traditional plowing. The ground is opened, planted, and injected with fertilizer, insecticide, and herbicide in one pass over a field. This method is shown in Slides 24 through 26. The results of these new methods are shown photographically in Slides 24 and 25 (notice the mulch in these slides) and graphically in Slide 26.

Less surface traffic occurs with hay crops, and permanent pasturelands require infrequent or no tillage and when well-managed, have moderately high infiltration rates. Heavy grazing, however, can produce compaction much like machinery traffic (Slide 27). Undisturbed forest lands are generally superior to all other systems in terms of infiltration.

Soil organic matter helps improve infiltration under vegetative cover. Organic matter encourages granular structure, thereby increasing the macropore space, especially in clay soils. Slide 28 shows two soils. Notice the differences between the high and low organic level in soil. The relationship between pore space, infiltration and types of soil is discussed in detail in Module 3, "Soil as a Treatment Medium". Under natural vegetation, almost all of the annual production of plant tissue is returned to the soil. Even with harvested crops, vegetative cover may still provide considerable organic matter additions. Corn produces an average of 4-6 tons per acre of above ground dry matter, some of which is left on the surface, as seen in Slide 29. Additionally, 2 to 3 tons per acre of organic material are added to the soil annually by the roots alone.

Vegetation also influences the infiltration rate through frozen soil by the presence of roots and decaying plant residue. At first it may seem that frozen soil should be impermeable to water. Some frozen soils, however, have infiltration rates that equal or even surpass values when not frozen. Bare or compacted soils, low in organic matter, tend to form concrete-like masses when frozen. In contrast, well-aggregated soils, high in organic matter, retain their porosity upon freezing and more freely accept water. Slide 30 shows application of waste on a frozen site. Although some soils may be highly permeable, biological activity and thus the renovative capacity of the site, decreases drastically at low temperatures and, therefore, waste loading rates must be reduced or stopped in winter.

We have been talking about how the vegetative cover affects the soil in relation to erosion and infiltration or in relation to application of water including wastewater and sludge. Once the wastewater has been applied to the soil/plant cover area, aerobic conditions are necessary for the rapid decomposition of organic matter in the wastewater and the prevention of offensive odors (Slide 31). Aerobic conditions are maintained by evaporation and transpiration. Evaporation provides for the loss of water at or close to the soil surface. Vegetative cover provides a means for water removal up to several feet below the surface as is diagrammed in Slide 32. Plant roots absorb water and nutrients from the soil. The water moves up through the plant body and is lost to the atmosphere from the leaves. Through this process, called transpiration, vegetation accelerates the drying and aeration of soils between wastewater applications.

Both evaporation and transpiration are functions of climatic conditions including temperature, precipitation, solar radiation, and wind. Transpiration, however, as is indicated in Slide 33, is also dependent on the availability of soil moisture and vegetation characteristics including rooting depth and seasonal pattern of both root and leaf development. Since it is not usually feasible to separate amounts of direct evaporation and transpiration, the two values are combined and referred to as evapotranspiration or ET (Slide 34). This value can obviously never exceed the maximum allowed by absorbed energy. Therefore, regional estimates of potential evapotranspiration, applicable to most crops, can be calculated empirically or from heat budget studies. This is discussed in detail in Module 8, "Climate and Wastewater Storage".

As the moisture content of the soil decreases, water becomes more difficult for plants to extract (Slide 35). Under a well managed application system, however, soil moisture availability will seldom restrict transpiration. Water availability is discussed in relation to pore space, in Module 3, "Soil as a Treatment Medium".

Rooting depth becomes increasingly important as the length of the resting period between wastewater applications increases. Moisture in the surface layers of the soil are the first to dry due to both direct evaporation and the fact that most plants have a maximum root density there (Slide 36).

As this layer dries, water will be drawn from successively deeper zones in accordance with rooting density. Overall root form and development capabilities of the root system are established by internal plant factors. Soil physical properties, however, control the extent to which these capabilities are expressed in particular soils or seasons. For example, as Slide 37 shows, alfalfa roots may reach depths of 20 feet or more on deep, workable prairie soils. In contrast, soils with dense sub-surface layers or shallow bedrock can restrict rooting to a few feet or less as in the plant on Slide 38. With frequent application of wastewater, rooting depth may also be restricted (Slide 39). This is because water is available close to the surface, making it possible for the roots to extract the necessary moisture for their needs at that level.

Seasonal patterns of vegetation development and farming practices cause differences in the transpiration rates among various crop plants. Slide 40 shows the daily ET rate for two cropping systems - corn followed by winter wheat and a mixed grass and alfalfa meadow. The meadow vegetation develops earlier and transpiration reaches a peak in May. The corn is not even planted until May so that peak transpiration rates are not reached until August.

Until this point, we have been discussing factors dealing with vegetative cover and water. That is runoff, infiltration, and evapotranspiration. However, municipal effluents and sludges contain most, if not all, of the essential nutrients for plant growth though not necessarily in balanced proportions. This is shown in Slide 41. Two of these nutrients, nitrogen and phosphorus, are of particular interest, since, in excess they are the major causes of eutrophication - pollution of surface waters. Vegetative cover uses these and other nutrients and thus plays an integral role in the renovation of applied waste.

As can be seen in Slide 42, the actual quantity of nutrients removed by vegetation varies widely with the type of plant cover and the harvested yield. These are highly generalized values for the harvest removal of nitrogen and phosphorus. Nitrogen is absorbed in greatest quantities by certain species of grasses. This fact, combined with the advantages of grass in

promoting infiltration and preventing erosion, is well worth noting. Also note that harvesting only selected parts of the vegetation, like corn grain or wheat grain, removes less of the nutrient than does harvesting the whole available plant. Notice that the scale for the nitrogen removed per acre, and the scale for the amount of phosphorus removed per acre differ by a factor of ten.

Nutrient uptake is often a function of loading rate; the relationship, however, is not linear and the higher application rates result in a lower percent removal. This is seen in Slide 43. Furthermore, when much of the applied nitrogen is in organic form as in sludges, it will not be available for plant uptake until after microbial decomposition, depicted in Slide 44.

Thus, the form, as well as the total amount of nutrient added in the waste, must be considered when assessing the fate of nutrients in the land application system.

The importance of nutrient uptake by vegetation varies among application systems. With crop irrigation schemes, as shown in Slides 45 and 46, nutrient removal through plant harvest is a primary means of renovating waste. In such systems, plant nitrogen requirements are generally the limiting factor and dictate the allowable waste loading rate. In overland flow systems, seen in Slides 47 and 48, both crop uptake and denitrification play major roles in nitrogen removal; phosphorus removal, however, may depend heavily on vegetation uptake since wastewaters may have only minimal contact with appreciable soil volumes to adsorb the phosphorus. Under rapid infiltration, as seen in Slides 49 and 50, the amount of nutrients removed by plants is often minor compared to total loading. Vegetative cover, in this case, serves mainly to maintain the high infiltration capabilities of the soil.

Although forest systems (Slide 51) are generally superior to all other systems in infiltration rates, the nutrient relationships of forest systems are more difficult to assess than with agronomic crops. This is due to the length of time involved in forest cropping rotations and the fact that natural forests often contain several different species and ages. Nutrient uptake during a single growing season may be comparable to agricultural crops (Slide 52). Much of this uptake, however, is redeposited annually rather than harvested. Thus, an annual uptake of 80 lbs of N per acre may result in only 15-20 lbs/acre retention (Slide 53). Furthermore, retention decreases

as trees reach maturity and, in old stands, may approach zero.

Traditional harvest results in only the stemwood being removed at intervals of 40 to 100 years, the nutrient rich branches, leaves, and roots being left on the site, as seen in Slide 54. Decay of these releases their nutrient stores back into the soil. At present, there is increasing interest in more intensive harvests, sometimes involving chipping and removal of the entire above-ground crop at intervals as short as 5-20 years, as seen in Slide 55. Although this would result in more nutrient removal from a land application site, it would introduce additional management considerations such as increased erosion from the bare soil. The potential for combining waste application with forest crops is worthy of further discussion and is dealt with in detail in Module 13, "Non-crop and Forest Systems".

Up to this point, this module has dealt with the effect of vegetative cover on the treatment process, and as a part of the process. There are two side benefits that can result from the vegetative cover that have little to do with the actual treatment process itself. The first benefit is economic; the second is aesthetic (Slide 56). The direct sale of crops and livestock or the leasing of land to local farmers produces income. This income is generally determined by local market conditions and crop yields and should be determined, therefore, from local sources.

In general, the sale of grain will produce a higher return than the sale of perennials such as hay. Grain crops, however, require greater inputs of labor and machinery as well as a higher level of expertise (Slide 57). The greater machinery movement over the field can seriously affect erosion and infiltration.

The return from existing land treatment systems has commonly offset only a part of the overall operation and maintenance expenses. Returns have ranged from 8% of operation and maintenance at Paris, Texas to a projected 70% in Muskegon, Michigan (Slide 58).

Apart from its operational and economic benefits, vegetative cover has evident aesthetic value (Slides 59 through 64). The potential appearance of a waste application site may well effect its overall acceptance. You compare. Vegetation might be selected for its utility as well as appearance. For

example, aerosol drift from sprinkler systems may be reduced by a border of trees or tall shrubs. As these slides indicate a waste treatment area can be considered an asset to a community or a place to avoid. The vegetative cover can be a selling point for a land treatment system. In fact, it can be the key in convincing a skeptical community. In general, appropriate use and design of vegetative cover is an alternative to having a treatment site regarded as a necessary nuisance or something to be hidden from public view.